

What if $b\bar{b}$ does not dominate the decay of the Higgs-like boson?

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Abstract

The dominant decay mode of standard model Higgs at 126 GeV $b\bar{b}$ suffers from severe SM background at the LHC even in associated productions Wh_{SM} or Zh_{SM} . The precision measurement of $\text{BR}(\phi \rightarrow b\bar{b})$ requires more data to reduce its large error bar. We investigate the possibility of this channel with largest uncertainty not dominating the decay of Higgs-like boson discovered at the LHC. In such scenarios, the Higgs signal shows highly suppressed $b\bar{b}$, slightly reduced $\tau^+\tau^-$ and moderately enhanced gauge bosons comparing with the SM predictions. The model requires two different sources of electroweak symmetry breaking and radiative correction to m_b strongly enhanced. However, large reduction in $b\bar{b}$ usually results large enhancement in $\tau^+\tau^-$ mode in particular. The reduction of $\tau^+\tau^-$ therefore implies that a new decay mode is inevitable. We find that a non-decoupling MSSM Higgs decay into lighter Higgs $H \rightarrow hh$ may fit the signature. Here, MSSM H is identified as the 126 GeV resonance while h is below $M_H/2$ and can evade the direct search bound at LEP II and Tevatron. Large PQ and R symmetry breaking effects mediated by strong interaction can strongly enhance radiative corrections in m_b . However, the scenario can only be realized in highly fine-tuned parameter region where G_{Hhh} is tiny. Nevertheless, we discuss the discovery potential of this highly fine-tuned $H \rightarrow hh$ at the LHC.

The ATLAS and CMS collaborations at the CERN Large Hadron Collider (LHC) has discovered a Higgs-like boson ϕ of 126 GeV via various channels. It was first seen via the two cleanest channels, the di-photon ($gg \rightarrow \phi \rightarrow \gamma\gamma$) and the four-lepton ($gg \rightarrow \phi \rightarrow ZZ^* \rightarrow \ell_i^+ \ell_i^- \ell_j^+ \ell_j^-$ with $i, j = e^\pm, \mu^\pm$) modes[1] and later in the di-lepton ($gg \rightarrow \phi \rightarrow WW^* \rightarrow \ell_i^+ \nu_i \ell_j^- \bar{\nu}_j$) with mass range consistent with the four-lepton measurement [2]. Both collaborations [3, 4] recently also updated their studies on spin and parity and a CP-even spin-zero state $J^P = 0^+$ is preferred based on the data of four lepton channel. In addition, both collaborations have also reported the boson decaying into tau pairs, $\phi \rightarrow \tau^+ \tau^-$. This is the first evidence at the LHC that the Higgs-like boson actually couples to SM fermions. On the other hand, for a SM Higgs boson of 126 GeV, more data is required to reduce the large error bar in the dominant decay channel $h_{\text{SM}} \rightarrow b\bar{b}$. $h_{\text{SM}} \rightarrow b\bar{b}$ from gluon fusion suffers tremendous QCD background so it can only be searched through associated productions $W\phi$ and $Z\phi$ with leptonic decays of W/Z . Due to large uncertainties in b -jet measurements, the reconstructed boson mass lies in a broad range. There also exists large uncertainties in missing transverse energy \cancel{E}_T measurements. In addition, large gluon PDF results in huge number of b -jets at the LHC which leads signals of $W/Z + \phi \rightarrow b\bar{b}$ to suffer from severe background. Both collaborations have seen enhancement in di-photon channels with respect to the SM prediction and moderate reduction in the $\tau^+ \tau^-$ channel. In the di-lepton and four-lepton channels, results from two collaborations largely overlap. In the $b\bar{b}$ channel, the central values are very different and the result of ATLAS collaboration still has very large uncertainty. In term of R , the ratio between observation and SM prediction $R \equiv \sigma_{\text{obs.}}/\sigma_{\text{SM}}$, latest results of $b\bar{b}$ from both collaborations are

$$\begin{aligned} \text{ATLAS} : & -0.4 \pm 1.1(13 \text{ fb}^{-1}@8 \text{ TeV}, 4.7 \text{ fb}^{-1}@7\text{TeV}) \\ \text{CMS} : & 1.1 \pm 0.6(12.1 \text{ fb}^{-1}@8 \text{ TeV}, 5 \text{ fb}^{-1}@7\text{TeV}) \end{aligned} \quad (1)$$

Given its large uncertainty, it is worth investigating the possible scenario if $b\bar{b}$ channel does not dominate the Higgs decay. To illustrate the feature, we use ATLAS central values to fit other channels and assume that the $b\bar{b}$ is highly suppressed. The R -values are

$$\begin{aligned} R_{\gamma\gamma}^{\text{ATLAS}} &= 1.8 \pm 0.5(5.9 \text{ fb}^{-1}@8 \text{ TeV}, 4.8 \text{ fb}^{-1}@7\text{TeV}) \\ R_{4\ell}^{\text{ATLAS}} &= 1.4 \pm 0.6(5.8 \text{ fb}^{-1}@8 \text{ TeV}, 4.8 \text{ fb}^{-1}@7\text{TeV}) \\ R_{2\ell 2\nu}^{\text{ATLAS}} &= 1.5 \pm 0.6(13 \text{ fb}^{-1}@8 \text{ TeV}) \\ R_{\tau^+ \tau^-}^{\text{ATLAS}} &= 0.7 \pm 0.6(13 \text{ fb}^{-1}@8 \text{ TeV}, 4.6 \text{ fb}^{-1}@7\text{TeV}) \end{aligned} \quad (2)$$

In this paper, we study whether the scenario of highly suppressed $b\bar{b}$, slightly reduced $\tau^+\tau^-$ with moderately enhanced gauge boson pairs can be realized in simple models.

One important property of the SM Higgs h_{SM} is that it couples SM fermions with strengths proportional to their masses. At Hadron colliders, τ -lepton and b -jets are two leading and best identifiable final states in Higgs decaying into SM fermions. Therefore, the comparison between these viable modes play an important role to test whether the Higgs-like boson is the SM Higgs. Within SM, the ratio X between branching fraction in $\tau^+\tau^-$ and $b\bar{b}$ channels is

$$X \equiv \frac{\text{BR}(h_{\text{SM}} \rightarrow \tau^+\tau^-)}{\text{BR}(h_{\text{SM}} \rightarrow b\bar{b})} = \frac{\Gamma(h_{\text{SM}} \rightarrow \tau^+\tau^-)}{\Gamma(h_{\text{SM}} \rightarrow b\bar{b})} \simeq \frac{m_\tau^2}{N_C m_b^2 K}, \quad (3)$$

where m_b , m_τ are the bottom quark and tau lepton masses respectively, $N_C = 3$ is the color factor. K accounts for QCD corrections of Higgs decaying into light quark states which is typically $1/1.5 \sim 1/2$ for Higgs mass of $\mathcal{O}(120 \text{ GeV})$. For $M_{h_{\text{SM}}} = 126 \text{ GeV}$, $X \sim 1/10$. In $SU(5)$ Grand Unification, τ and b arise from the same multiplet 5^c . The ratios X in Eq. 3 in models originated from $SU(5)$ are naturally similar to the SM value. To obtain the highly reduced width of $H \rightarrow b\bar{b}$, additional radiative corrections must reduce the tree-level Yukawa couplings and split b and τ . In order for radiative corrections to reduce tree level couplings, a second sector for electroweak symmetry breaking must exist. In Type-II Two-Higgs-Doublet-Models (2HDM), both b and τ masses arise from $\langle H_d \rangle$ at tree level but there exist contributions of $\langle H_u \rangle$ -type from the mixing term $M_{12}^2 H_u H_d$ which naturally leads reduction in Yukawa couplings. In SM, QCD correction of $\Gamma(h_{\text{SM}} \rightarrow b\bar{b})$ can reduce the Born value from pole mass by 35% to 50% and we expect similar mechanism in new physics models. A particularly interesting mechanism lies in supersymmetric models where radiative corrections through strong interaction are related to breaking of two symmetries, Peccei-Quinn symmetry and R -symmetry and both symmetries must be broken at $\mathcal{O}(\text{TeV})$. For instance, the mixing term $H_u H_d$ in Type-II 2HDM exists in soft supersymmetry breaking Lagrangian as $B\mu$ -term which breaks both PQ and R -symmetry. Due to strong interaction and large gluino mass, radiative corrections to m_b are typically significantly enhanced. This feature is highly non-trivial in beyond SM theories [5].

Supersymmetric models are naturally Type-II 2HDM due to holomorphic condition of superpotential and cancelations for $[SU(2)_L]^2 U(1)_Y$ and Witten anomalies. The SM fermion masses arise at tree level in superpotential

$$W = y_u Q u^c H_u + y_d Q d^c H_d + y_\ell \ell_L^c H_d + \mu H_u H_d \quad (4)$$

where y_u , y_d and y_ℓ are tree level Yukawa couplings of up, down quarks and charged leptons respectively. y_d and y_ℓ are proportional to $\tan \beta \equiv v_u/v_d$. On the other hand, $Qd^c\bar{H}_u$ or $\ell e^c\bar{H}_u$, which are forbidden by the holomorphic condition of superpotential, is invariant under the SM gauge symmetries and can be generated as radiative corrections. Besides the SM gauge symmetries, listed in Table 1 are charge assignments of the particles under two additional symmetries in supersymmetric theory, Peccei-Quinn (PQ) symmetry and R -symmetry¹. PQ-symmetry which forbids the bare- $H_u H_d$ term in superpotential is explicitly broken by the μ -term and $B\mu$ -term. R -symmetry corresponds to the chiral symmetry that protects gaugino masses from being generated in the supersymmetric limit. R -symmetry breaking terms in the soft supersymmetry breaking Lagrangian are gaugino masses, A -terms and $B\mu$ -term.

Field	Q	u^c	e^c	d^c	ℓ	H_u	H_d	θ
R -charge	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{3}{5}$	$\frac{3}{5}$	$\frac{4}{5}$	$\frac{6}{5}$	1
PQ	0	0	0	-1	-1	0	1	0

TABLE I. Charge assignment under R -symmetry and Peccei-Quinn symmetry.

Using charge assignments in Table 1, one can substitute them into calculation of effective coupling $Qd^c\bar{H}_u$ as

$$R[Qd^c\bar{H}_u] : \quad \frac{1}{5} + \frac{3}{5} - \frac{4}{5} = 0 \quad (5)$$

$$\text{PQ}[Qd^c\bar{H}_u] : 0 + (-1) + 0 = -1 . \quad (6)$$

These equations clearly show that $Qd^c\bar{H}_u$ breaks both R -symmetry and PQ symmetry. Therefore, radiative corrections of m_b or m_τ in supersymmetry are proportional to production of μ and gaugino masses or A -term.

On the other hand, for the SM Higgs h_{SM} with $M_h = 126$ GeV, $b\bar{b}$ dominates 60% of the Higgs decay with $\Gamma(h_{\text{SM}} \rightarrow b\bar{b}) = 2.6 \times 10^{-3}$ GeV. Significant reduction in $\Gamma(h_{\text{SM}} \rightarrow b\bar{b})$ then results in significant reduction in total width and enhance the WW/ZZ and di-photon if no new decay channels exists. In particular, if y_τ reduction is not as large as y_b , $\text{BR}(\phi \rightarrow \tau^+\tau^-)$ can also be significantly enhanced. However, since Eq.2 shows the $R_{\tau^+\tau^-} \sim 70\%$, a new decay mode is then inevitable.

¹ To explicitly determine the charge assignments, we use $SU(5)$ convention in the Table 1.

Two immediate options that can evade the current searches are the invisible decay of Higgs and the Higgs decaying into lighter scalars. The first option may be connected to the Dark Matter of the model but it is strongly constrained by requiring the relic density not to be over-abundant. For the second option, $h \rightarrow AA$ in NMSSM [6, 7] or $H \rightarrow hh$ [8] in non-decoupling MSSM [9–19] may provide a simple realization. In this paper, we focus on the $H \rightarrow hh$ possibility of non-decoupling MSSM. On the other hand, in large parameter space, once $H \rightarrow hh$ decay is open, $\Gamma(H \rightarrow hh)$ is usually much larger than the other channels and may completely dominate the decay of H . Therefore, $\Gamma(H \rightarrow hh)$ needs to be highly fine-tuned to be at the comparable level as the width of SM Higgs decaying into bottom pair $\Gamma(h_{\text{SM}} \rightarrow b\bar{b})$. In non-decoupling MSSM first proposed by [9], H is identified as the resonance at 126 GeV and a much lighter h can evade direct searches in LEP II and Tevatron experiments by suppressing ZZh coupling and thus production of Zh . To reduce the ZZh coupling which is the vacuum expectation value (v_{ev}) of h , simple realization is to let h be the H_d -like boson since large m_t naturally requires large v_u . Given h is a mixture state as $-\sin\alpha(\text{Re } H_d) + \cos\alpha(\text{Re } H_u)$, this scenario prefers $\sin\alpha \simeq -1$ with large $\tan\beta$ which suppresses the v_d . In the limit of large $\tan\beta$ as $\sin\beta \rightarrow 1$, $\sin\alpha \rightarrow -1$ gives the $g_{ZZh} = \sin(\beta - \alpha)$ approaches zero. In large parameter region, the partial width $\Gamma(H \rightarrow hh)$ are typically several orders of magnitude higher than $\Gamma(h_{\text{SM}} \rightarrow b\bar{b})$ and consequently $H \rightarrow hh$ completely dominate the H decay there. Therefore, visible decay channels of $\gamma\gamma$, $ZZ^* \rightarrow 4\ell$ and $WW^* \rightarrow 2\ell 2\nu$ require that the $\Gamma(H \rightarrow hh) \sim \Gamma(h_{\text{SM}} \rightarrow b\bar{b}) \sim 2 \times 10^{-3} \text{ GeV}$.

Our numerical analysis are performed with the help of *FeynHiggs* 2.9.2 [20] with *HiggsBounds* 3.8.0 [21] and *SUSY_Flavor* 2.01 [22]. We require that

- $M_H : 125 \pm 2 \text{ GeV}$;
- $R_{\gamma\gamma} = \sigma_{\text{obs}}^{\gamma\gamma} / \sigma_{\text{SM}}^{\gamma\gamma} : 1 \sim 2$;
- Combined direct search bounds from HiggsBound3.8.0;
- $\text{BR}(B \rightarrow X_s \gamma) < 5.5 \times 10^{-4}$;
- $\text{BR}(B_s \rightarrow \mu^+ \mu^-) < 6 \times 10^{-9}$.

In *FeynHiggs*, Higgs boson masses are calculated to full two-loop. To illustrate the qualitative feature here, we use the leading one-loop expression with only contributions of top Yukawa couplings. Radiative corrections to the Higgs boson mass matrix elements are [5, 24]

$$\Delta\mathcal{M}_{12}^2 \sim \Delta\mathcal{M}_{11}^2 \sim 0 \tag{7}$$

and

$$\Delta\mathcal{M}_{22}^2 \sim \epsilon = \frac{3m_t^4}{2\pi^2 v^2 \sin^2 \beta} \left[\log \frac{M_{\text{SUSY}}^2}{\tilde{m}_t^2} + \frac{X_t^2}{2M_{\text{SUSY}}^2} \left(1 - \frac{X_t^2}{6M_{\text{SUSY}}^2} \right) \right] \quad (8)$$

where $X_t = A_t - \mu \cot \beta$ and $M_{\text{SUSY}} = (M_{\tilde{t}_1} + M_{\tilde{t}_2})/2$.

With one loop correction , the mixing angle α can be obtained

$$\frac{\tan 2\bar{\alpha}}{\tan 2\beta} = \frac{M_A^2 + m_Z^2}{M_A^2 - m_Z^2 + \epsilon/\cos 2\beta} . \quad (9)$$

The trilinear coupling among neutral Higgs bosons Hhh , in unit of $-i\frac{m_Z^2}{v}$, is given in

$$\lambda_{Hhh} = [(2 \sin 2\alpha \sin(\beta + \alpha) - \cos 2\alpha \cos(\beta + \alpha))] , \quad (10)$$

with one-loop correction

$$\Delta\lambda_{Hhh} = 3 \frac{\epsilon}{m_Z^2} \frac{\sin \alpha}{\sin \beta} \cos^2 \alpha . \quad (11)$$

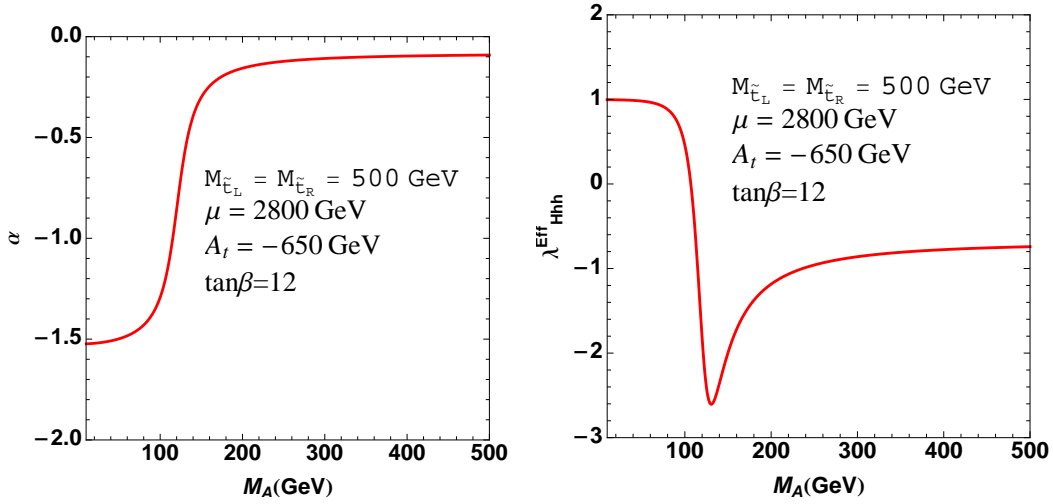


FIG. 1. (a) Mixing angle α and (b) normalized Hhh coupling λ_{Hhh} with respect to M_A , the other parameters are fixed as shown explicitly in the plots.

Plotted in Fig. 1 are the mixing angle α and normalized Hhh coupling λ_{Hhh} with respect to M_A using one-loop result from Eqs 9, 10, 11 while the other parameters are fixed as in [18]

$$\mu = 2800 \text{ GeV}, \tan \beta = 12, M_{\tilde{t}_L} = M_{\tilde{t}_R} = 500 \text{ GeV}, A_t = -650 \text{ GeV} . \quad (12)$$

Around $\alpha \sim -\pi/4$, λ_{Hhh} vanishes. Therefore, in order to get a highly reduced λ_{Hhh} , one can choose this fine-tuned region of M_A .

Explicitly the Yukawa couplings for b and τ are [5]

$$\mathcal{L} = y_b H_d^0 \bar{b} b + \Delta y_b H_u^0 \bar{b} b + y_\tau H_d^0 \bar{\tau} \tau + \Delta y_\tau H_u^0 \bar{\tau} \tau, \quad (13)$$

where Δy_i stand for corrections to the Yukawa couplings and fermion masses arise from

$$m_b = y_b v_d + \Delta y_b v_u, \quad m_\tau = y_\tau v_d + \Delta y_\tau v_u. \quad (14)$$

For simplicity, one can define

$$y_b = \frac{\sqrt{2} m_b}{v \cos \beta (1 + \Delta_b)}, \quad y_\tau = \frac{\sqrt{2} m_\tau}{v \cos \beta (1 + \Delta_\tau)}. \quad (15)$$

where $\Delta_b = \Delta y_b \tan \beta / y_b$ ($\Delta_\tau = \Delta y_\tau \tan \beta / y_\tau$) is the relative bottom (tau) mass correction. In supersymmetric theory, leading contributions to Δ_b and Δ_τ are

$$\Delta_b = \mu \tan \beta \left[\frac{g_3^2 M_3}{6\pi^2} I(M_3^2, m_{b_1}^2, m_{b_2}^2) + \frac{y_t^2 A_t}{16\pi^2} I(\mu^2, m_{t_1}^2, m_{t_2}^2) \right], \quad (16)$$

$$\Delta_\tau = \mu \tan \beta \left[\frac{g_1^2 M_1}{16\pi^2} I(M_1^2, m_{\tilde{\tau}_1}^2, m_{\tilde{\tau}_2}^2) + \frac{g_2^2 M_2}{16\pi^2} I(M_2^2, \mu^2, m_{\tilde{\nu}_\tau}^2) \right], \quad (17)$$

where the positive-definite symmetric function I is

$$I(x, y, z) = -\frac{xy \ln(x/y) + yz \ln(y/z) + zx \ln(z/x)}{(x-y)(y-z)(z-x)}. \quad (18)$$

In Eq.16 and Eq.17, Δ_b and Δ_τ are always proportional to the PQ-symmetry breaking term μ . However, R -symmetry breaking effects in Δ_b and Δ_τ are very different. Δ_b is generated through strongly interaction and enhanced by large gluino mass M_3 . Δ_τ only receives correction via electroweak interaction with bino mass M_1 . In addition, large R -symmetry breaking $y_t^2 A_t$ also contributes. As discussed in [18], squark loop may significantly cancel the contribution of light charged Higgs to flavor violation, in particular in $b \rightarrow s$ transition. Given the charged Higgs is at similar scale as $M_H = 126$ GeV in non-decoupling MSSM, scenario with light top squark can survive all the flavor physics bounds. In $b \rightarrow s\gamma$, helicities for involved quark states must be flipped. This corresponds to a case with both chiral symmetry $U(3)_Q \times U(3)_d$ breaking and electroweak symmetry breaking and is exactly the same as the symmetry breaking in m_b generation. The supersymmetric contribution to $b \rightarrow s\gamma$ is therefore exactly the same as supersymmetric correction to m_b . Large PQ-symmetry and R -symmetry breaking is also required to cancel $b \rightarrow s\gamma$ [18]. The same parameter choice can also improve the flavor violation in $B_s \rightarrow \mu^+ \mu^-$.

We use one benchmark point to illustrate the feature discussed previously and discuss the collider phenomenology. Without loss of generality, we fix masses of the sfermions as ²

$$\begin{aligned} M_{\tilde{Q}_{1,2}} &= M_{\tilde{u}_{1,2}} = M_{\tilde{d}_{1,2,3}} = M_{\tilde{L}_{1,2,3}} = M_{\tilde{e}_{1,2,3}} = 1 \text{ TeV} , \\ M_{\tilde{Q}_3} &= M_{\tilde{t}} = 500 \text{ GeV} \end{aligned} \quad (19)$$

and gauginos as

$$M_1 = 200 \text{ GeV}, M_2 = 400 \text{ GeV}, M_3 = 1200 \text{ GeV} . \quad (20)$$

Other parameters of benchmark point are listed as

$$\mu = 2800 \text{ GeV}, A_t = -630 \text{ GeV}, M_A = 141 \text{ GeV}, \tan \beta = 11 . \quad (21)$$

With *FeynHiggs*, we compute the corresponding R -values and Higgs boson masses of benchmark point in Eq.22 and Eq.23

$$M_h = 20.7 \text{ GeV}, M_H = 123.3 \text{ GeV} , \quad (22)$$

$$R_{\gamma\gamma} = 1.34, R_{ZZ} = R_{WW} = 1.74, R_{b\bar{b}} = 0.038, R_{\tau^+\tau^-} = 0.72 . \quad (23)$$

At hadron colliders, the leading three production channels of H are via gluon fusion, weak boson fusion as well as associated production.

$$pp \rightarrow H, jjH, WH, ZH \quad (24)$$

H can decay into $ZZ^* \rightarrow 4\ell, \gamma\gamma, \tau^+\tau^-$ and $WW^* \rightarrow 2\ell 2\nu$ just as SM Higgs boson does. The corresponding events number in the final states respect to the SM Higgs boson prediction are given in Eq.23. However, $H \rightarrow b\bar{b}$ in our benchmark scenario is highly suppressed with decay BR only 4% of the SM prediction. On the other hand, H has significant decay BR into hh states as

$$\text{BR}(H \rightarrow hh) = 39.3\% . \quad (25)$$

At $\tan \beta \sim 10$, v_{ev} of a H_d -like h is small thus the coupling hWW . The reduction in hWW also results in partial width $\Gamma(h \rightarrow \gamma\gamma)$ is much smaller than the SM value. h dominantly decay into $b\bar{b}$ and $\tau^+\tau^-$ states as

$$\text{BR}(h \rightarrow b\bar{b}) = 85.8\%, \text{BR}(h \rightarrow \tau^+\tau^-) = 13.6\% . \quad (26)$$

² Scenarios with light stau [23] can further enhance $R_{\gamma\gamma}$ but may reduce the M_H .

Then H can decay into $4b$, $4\tau^\pm$ or $2b2\tau^\pm$ with corresponding BR shown in parenthesis

$$H \rightarrow hh \rightarrow b\bar{b}b\bar{b} \text{ (28.9\%)}, b\bar{b}\tau^+\tau^- \text{ (4.6\%)}, \tau^+\tau^-\tau^+\tau^- \text{ (0.73\%)}. \quad (27)$$

Search of Higgs boson into $4b$, $2b2\tau^\pm$ and $4\tau^\pm$ final states have been discussed in context of NMSSM [6, 7] as for $h \rightarrow aa$. [6] studied Higgs boson h from gluon fusion and Weak boson fusion production with exactly the same final state as in our case. It typically requires 14 TeV LHC with 300 fb^{-1} to claim a $3\text{-}5\sigma$ discovery due to large SM background. To improve the signal over background ratio, [7] focuses on the search of $h \rightarrow aa$ through associated production Wh/Zh and can reduce the required data to 100 fb^{-1} . For the benchmark point in this paper, we have the associated production at 14 TeV LHC as

$$\sigma(pp \rightarrow WH) = 1.59 \text{ pb}, \quad \sigma(pp \rightarrow ZH) = 0.94 \text{ pb} \quad (14 \text{ TeV}) \quad (28)$$

the gluon fusion production rate for 8 TeV and 14 TeV LHC as

$$\sigma(gg \rightarrow H)(8 \text{ TeV}) = 22.18 \text{ pb}, \quad \sigma(gg \rightarrow H)(14 \text{ TeV}) = 56.31 \text{ pb}. \quad (29)$$

We estimate our signal rates, for instance, $\ell\nu + 4b$ or $\ell\nu + 2b2\tau^\pm$ without any cut,

$$\begin{aligned} \sigma(pp \rightarrow WH \rightarrow \ell\nu + b\bar{b}b\bar{b}) &= 102.5 \text{ fb} \\ \sigma(pp \rightarrow WH \ell\nu + b\bar{b}\tau^+\tau^-) &= 16.25 \text{ fb} \end{aligned} \quad (30)$$

which is about 30% less than the benchmark points of 120 GeV Higgs studied in [7]. We argue that our benchmark point may require a little more data than claim in [7].

For gluon fusion production, we want to point out that one particular interesting final states may help the search. If H is produced via gluon fusion and decay into four tau final states, one can choose the final states as two same-sign leptonic taus with two hadronic taus

$$gg \rightarrow H \rightarrow hh \rightarrow \tau^+\tau^-\tau^+\tau^- \rightarrow \tau_\ell^\pm \tau_\ell^\pm \tau_h \tau_h \quad (31)$$

which corresponds to same-sign di-lepton with one hadronic tau tag. The production rate without any tag efficiency or kinematic cut is then

$$56.31 \text{ pb} \times 0.73\% \times 35\% \times 35\% \times 65\% \times 65\% \times 2 \simeq 42.6 \text{ fb} \quad (32)$$

which made the final state also possible to search at 100 fb^{-1} . On the other hand, this study requires much more realistic simulation including detector effects and polarized tau decay treatment before drawing more convincing conclusions. We leave this study to experimental colleagues.

In summary, we discuss the possibility of $b\bar{b}$ final states with largest uncertainty being replaced by another final state. In such scenarios, the Higgs signal shows highly suppressed $b\bar{b}$, slightly reduced $\tau^+\tau^-$ and moderately enhanced gauge bosons comparing with the SM predictions. The model requires two different sources of electroweak symmetry breaking and radiative correction to m_b strongly enhanced. However, large reduction in $b\bar{b}$ usually results large enhancement in $\tau^+\tau^-$ mode in particular. The reduction of $\tau^+\tau^-$ therefore implies that a new decay mode is inevitable. We find that a non-decoupling MSSM Higgs decay into lighter Higgs $H \rightarrow hh$ may fit the signature. Here, MSSM H is identified as the 126 GeV resonance while h is below $M_H/2$ and can evade the direct search bound at LEP II and Tevatron. However, the scenario can only be realized in highly fine-tuned parameter region where G_{Hhh} is tiny. Therefore, we argue the highly suppressed $b\bar{b}$ is not likely. Nevertheless, we in the end discuss the discovery potential of $H \rightarrow hh$ at the LHC which would require more than 14 TeV LHC with more than 100 fb^{-1} of data to see any over three sigma deviation.

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